Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Digital Broadcast Copy	)	MB Docket No. 02-230
Protection	)	
	)	

REPLY COMMENTS OF RAFFI KRIKORIAN

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1 Introduction

My name is Raffi Krikorian, and I am currently enrolled as a graduate student at the Massachusetts Institute of Technology (MIT) pursuing a Masters Degree at The Media Lab in the Physics & Media Group studying and specializing in large, distributed, networked, and emergent systems. Before entering the program, I was an undergraduate researcher at the MIT Media Lab where I helped design and build Hive[1], I worked as a programmer at Popular Power[2] creating a distributed computational engine for the Internet, as a free-lance technical writer for the O'Reilly Network[3] where I wrote articles on Java[4] security and C#[5] programming, and as programmer specializing in peer-to-peer (P2P) and networking technology. Many would call me an authority on these subjects.

The initial comments of the Motion Picture Association of America (MPAA), et al., in this docket, assert that the Digital Television (DTV) transition will create a series of risks to their intellectual property interests, and propose the "broadcast flag" in order to address those risks. They provide a laundry-list of new risks from clear-text free-over-the-air Advanced Television Standards Committee (ATSC) broadcasts, including the prospect of redistribution of captured ATSC programming by:

1. electronic mail
2. "shared folders"
3. a web site, and by
4. P2P networked file-sharing software[6]

As a skilled and experienced technologist, I greeted these claims with immense skepticism as they seemed at direct odds with my longtime experience with designing, deploying, and using P2P and networked applications. In response to

[1] "Hive: Distributed Agents for Networking Things", Minar N., Gray M., Roup O., Krikorian R., Maes P. IEEE Concurrency, April-June 2000.

[2] `http://www.popularpower.com`

[3] `http://www.oreillynet.com`

[4] `http://www.javasoft.com`

[5] `http://msdn.microsoft.com/vcsharp/`

[6] See MPAA Comments, pages 6-8. The MPAA notes that "...digital broadcast television content can easily be redistributed via retransmission over networks like the Internet by such means as rebroadcasting, hosting files on a web server, or peer-to-peer file trafficking."

my skepticism, I undertook a series of experiments in recording and attempting to redistribute ATSC terrestrial broadcast programming. The results of my research are presented below.

2 Experimental Setup

For my research, I installed a Hauppauge WinTV-HD PCI board[7] into my Athlon XP 2700+ desktop computer running Microsoft Windows XP[8]. I chose this board because it allows me to capture a demodulated ATSC stream onto my hard drive. My desktop PC is attached to a fairly typical home computer network which consists of a 100 megabit (100 base-TX) Ethernet connection between the wired computers, an 802.11b (WiFi) wireless network for laptop computers, and a residential broadband cable modem connection that delivers a 1.5 megabit downstream connection and a 800 kilobit upstream connection[9] to the Internet. The 100 base-TX network switches used for my wired Ethernet network commonly cost less than $50, while the WiFi equipment used for my wireless network is commonly available for less than $100.

I attempted to determine whether any of MPAA's claims about the ease of redistribution were qualitatively correct, and to gather quantitative evidence in support of my determination. I gathered all the resources to attempt all the distribution methods that MPAA suggested were feasible. I tried all the distribution methods, except explicitly attempting to share the content with the public on a P2P network. Most P2P file sharing tools place me into an uncontrolled environment – had I started to share my recorded content with one of them, I might have unwittingly distributed the recordings in a manner out of my control, and I did not want to be responsible for that. As I explain in detail below, I carefully set up my web serving experiment to provide the same data that most P2P file sharing tools with provide me.

[7]The WinTV-HD card is manufactured by Hauppauge Computer Works, Hauppauge, NY, and currently retails for around $300; it is one of the most popular means of watching digital television broadcasts on an ordinary personal computer.

[8]Similarly configured machines can be purchased today from vendors like Dell or Gateway for less than $4000.

[9]These numbers are advertised by my cable modem provider's brochure, but I have rarely experienced actual connection speeds matching this ideal performance. Also, according to the Residential Broadband Users' Association, most residential broadband connections have an average uplink connection speed of 200 kilobits, so my ability to send data to the Internet is, on average, 4 times faster than the mean.

3 Obtaining a terrestrial broadcast stream recording

On January 26, 2002, I decided that I would record Super Bowl XXXVII for my first experiment, as this was to be a sterling example of native 720p[10] programming that is available via terrestrial broadcasts[11]. Also, I love American football and I planned to watch *Alias* after the game[12].

I prepared my PC and my terrestrial TV antenna, to which my WinTV-HD card was connected, so that everything was ready for recording a broadcast. I tuned to the terrestrial DTV station WCVB-DT (channel 20), an ABC affiliate, and started receiving the 720p signal. Once I was convinced that the picture was coming in well, I waited until the start of the game. At 6:00pm Eastern time, I started the WinTV software application and began recording the HDTV stream as a TRP (transport) file. A pleasurable whir started as the hard drive spun up to life, dumping the stream to disk, and I watched the game on a standard (non-HDTV) analog television, as the WinTV 2000 recording software provided by Hauppauge does not allow the viewer to watch and record the stream at the same time[13]. When the credits started rolling on my television I stopped the recording on the PC. I examined the TRP file to see its size, and found that the five hour Super Bowl broadcast recording occupied 43 GB[14].

4 Attempting to redistribute the recording

4.1 Playing back the Super Bowl

I began by attempting to watch the recorded stream. I loaded it back up in the WinTV application and *voilà*! It was showing. Unfortunately, the software does not provide me the ability for me to fast forward or rewind – I had to watch it as if I

[10] 720 vertical lines progressively scanned.

[11] ABC's football programming has been criticized recently, because it is transmitted in 720p instead of 1080i (the format used by CBS for its own football programming).

[12] ABC broadcasts *Alias* and much of its other primetime programming in 720p widescreen format, whereas standard-definition analog broadcast and cable programming is usually "pan and scan".

[13] This limitation will presumably be overcome in the near future.

[14] ATSC streams provide for 19.4 megabits/sec for transmission.

were watching it live[15]. I tried to load the file into the Windows Media Player, but it would not open the file; rather, it complained that it could not find nor download a codec[16] that would play the TRP file. It seemed as though the only way to watch the recorded Super Bowl was to bring it up in the WinTV application. This would be useless if I wanted to watch the recording somewhere else, or if I wanted to give it to friends. So I investigated a little further.

An ATSC transport stream contains multiple MPEG-2 video and audio streams each encoded in 188 byte packets to allow a HDTV tuner to recover quickly from any errors in the reception of the stream. In order for this MPEG-2 data to be a little more useful, I needed somehow to convert this transport stream format into a more compliant one. After searching the World Wide Web, I located a software program that seemed to do just that. It would convert an ATSC transport stream into an ordinary standards-compliant MPEG-2 file. The discussions I read on the World Wide Web indicated that its output was sufficiently standards-compliant to allow playback with a wide range of software – that meant that I could open the converted recording and watch it using the software that came with my desktop's DVD player[17]. After converting the transport stream, I tried opening it up in the PowerDVD software and it opened right up and began to play. At this point, I could watch the Super Bowl on the same desktop on which I initially recorded it. Now, could I move it to anybody else's machine?

4.2 Moving the Super Bowl around my house network

Moving the stream over my Ethernet network to another desktop machine seemed like a possibility, so I gave that a try. I shared the file from my Windows XP machine, making it available on my house network; I then tried to play it on a second Windows XP machine, and it played back correctly, streaming over the wire within my house.

Could I stream it to a laptop roaming around on the wireless network, I wondered? I start up my Windows 2000 laptop, inserted a Lucent WaveLAN 802.11b PCMCIA wireless network adapter, connected to my wireless network, and at-

[15] Presumably, future versions of this software will provide more sophisticated playback features. In addition, because the ATSC broadcast is transmitted and recorded in open standard formats, a wide variety of independently-created software can potentially be used to play back ATSC recordings.

[16] Short for a compressor/decompressor program.

[17] Because DVDs are also encoded in MPEG-2, the computer's DVD software presumably feeds the DVD to the video card's MPEG-2 decoder chip for display.

tempted to use a DVD player program to play back the MPEG-2 file. No luck. The playback application on the laptop just stuttered and stuttered and stuttered. The behavior is easy to explain. IEEE 802.11b (the type of wireless network that is most widely deployed) can only transmit at a maximum of 11 megabits/sec (1.375 megabytes/sec)[18]. The result is that to transferring the HDTV program to a computer over 802.11b would take over twice as long as the program itself; my capture of the Super Bowl would take 10 hours to move over to my laptop (and that is assuming that the network is not already transmitting something and running at maximum capacity). I could not stream the video to my laptop and watch it in real time. However, I could stream the program to other computers on my wired network as they were interlinked with 100 Base-TX connections, giving significantly more than the nearly 19.4 megabits/sec which might be required for the transmission of the stream.

Now I could move the recording to another computer on my *wired* network in my apartment – but what about the rest of the people out on the Internet?

4.3 E-mailing the Super Bowl

I started up Microsoft Outlook, addressed an e-mail to my best friend, dragged and dropped `SuperBowl.mpg` into the e-mail and pushed "Send". And I waited.

And I waited.

And I waited.

What was happening while I waited? In order to e-mail the binary file[19], the e-mail client needs to convert it to base-64 characters[20] for MIME attaching. My computer slowed to a crawl while I watched the status of the e-mail client to find out when it would finally start mailing the file out. I left to make some tea.

About half an hour later, the status bar finally changed! And now it appeared as

[18] 802.11b is commonly configured, when deployed in offices and public spaces, to sacrifice speed for range, which slows it down to 2 megabits/sec, or 0.25 megabytes/sec.

[19] Most e-mail attachments are binary files. A binary file differs from a textual file as it may contain characters other than letters, numbers, and punctuation marks; a binary file is not meant to be read by people.

[20] ASCII characters usually occupy 8 bits to give them each values between 0 and 255 while Base-64 coding uses a 65 character subset of only printable characters. In order to make the conversion, a computer scans through the ASCII character input, and for every 6 bits, it outputs a printable character – this means the conversion causes the input to grow by 25%. For more information see N. Freed and N. Borenstein, RFC 2045, "Multipurpose Internet Mail Extensions (MIME) Part One: Format of Internet Message Bodies" (available at `ftp.rfc-editor.org/in-notes/rfc2045.txt`).

though the e-mail was making its way out of my computer and onto my network, presumably on its way to my outgoing mail server.

And I waited.

And I waited.

And this continued overnight.

The next morning (while it was still going), I did a back-of-the-envelope calculation to figure out what was going wrong. I knew I had approximately an 800 kilobit/sec uplink on my cable modem, and I had a 43 gigabyte file. Using the following formula (where N is the number of bits I want to send, S is the number of bits/sec my modem is capable of, and T is the number of seconds it takes to move those bits)

$$N \div S = T \tag{1}$$

I computed the theoretical minimum amount of time it would take the 43 GB file of the Super Bowl to move out of my computer network (which *at best* is an 800 kilobit/sec uplink):

$$43\text{GB} \times \frac{1024\text{MB}}{1\text{GB}} \times \frac{1024\text{KB}}{1\text{MB}} \times \frac{1024\text{B}}{1\text{KB}} \times \frac{8 \text{ bits}}{1\text{B}} = 369,400,000,000 \text{ bits}$$

Now, I need to transmit all the 3.694×10^{11} bits[21] through my cable modem connection:

$$3.69 \times 10^{11} \text{ bits} \div \left(\frac{800 \text{ kilobit}}{1 \text{ sec}} \times \frac{1024 \text{ bits}}{1 \text{ kilobit}}\right) \approx 450,000 \text{ seconds}$$

To move the entire Super Bowl through my cable modem, under ideal conditions as advertised by the cable modem vendor, would take just over 5 days[22]! But, there are a few things wrong with this estimation:

1. It is important to note that I was attempting to e-mail the file which is 43 GB large *before* Base-64 encoding. After Base-64 conversion, which is necessary in order to transmit the file as an attachment, the size will grow to about 53.75 GB which means the Super Bowl would take (according to formula 1) about six and a half days to move out of my broadband connection.

[21] According to some astronomers, the universe is 14 billion (1.4×10^{11}) years old, which is under half the number of bits that are contained in the HDTV broadcast of the Super Bowl.

[22] 4.50×10^5 seconds is about 7500 minutes, or about 312 and a half hours, or about 5 days.

2. The 800 kilobit/sec upstream data link connection is a far cry from the actual transfer rates ever attained on my network link. Because the Internet routes data through many different routers and connections between them, a "weakest link" scenario emerges: the slowest link determines the speed of the entire connection. Between my desktop computer and my outgoing mail server, data packets jump through 9 different connections[23] and the slowest link of the 9 determines the total speed of the connection. TCP/IP (the underlying network protocol control mechanism) also attempts to share and balance out the used bandwidth fairly between my and others' network use, so that I cannot monopolize the network capacity to the detriment of other users. The result is that, even though my connection is rated at 800 kilobits/sec, I never achieve the rated performance in practice.

I concluded that e-mailing the file from my home network was effectively impossible.

4.4 Posting it on the web

To get around the 25% Base-64 file encoding size increase when trying to transfer the MPEG-2 file as an e-mail attachment, I decided to try to post it on a web page hosted on my home network. I set up a web server[24] on my gateway machine

[23] A commonly found tool on most modern networked computers is traceroute which was invented as a way to list all the routers and to measure the packet timings between any two given computers on the Internet. Here is the output of that tool running between my desktop computer and my outgoing mail server:

```
1  10.16.224.1 (10.16.224.1)  13.157 ms  13.563 ms  12.538 ms
2  vl200.cat1b.sbo.ma.rcn.net (209.6.160.101)  8.656 ms  7.103 ms  182.971 ms
3  ge0-0-0.core1.sbo.ma.rcn.net (207.172.15.132)  15.923 ms  11.749 ms  22.740 ms
4  GE20-GE-GIGAPOPNE-RCN.NOX.ORG (192.5.89.29)  7.504 ms  8.031 ms  8.320 ms
5  192.5.89.90 (192.5.89.90)  7.291 ms  21.237 ms  15.845 ms
6  E19-RTR-2-BACKBONE.MIT.EDU (18.168.0.22)  16.993 ms  8.737 ms  7.718 ms
7  lexus.media.mit.edu (18.85.0.2)  11.115 ms  12.120 ms  35.019 ms
8  passport.media.mit.edu (18.85.3.98)  24.313 ms  13.681 ms  16.728 ms
9  bayer.media.mit.edu (18.85.2.138)  10.735 ms  10.037 ms  8.902 ms
```

As you can see, there exists 9 hops along the path from my house network to the Media Lab's outgoing mail server each with a varying response rate for packets going through them. While the packet timing (latency) is not a direct measure of the speed (throughput) of a link, a correlation can be drawn between longer response times and less capable or more congested network links.

[24] I used Apache, however there is effectively no difference between Apache or IIS or any other web server for this purpose. The open source Apache web server is available at `http://www.apache.org` and powers over 60% of web sites (as reported at `http://www.netcraft.com/Survey/Reports/0301`).

in my apartment[25]. I placed the MPEG-2 file into a directory to allow it to be downloaded from the Apache server, and I wrote a short web page including a link to facilitate downloads. Then I gave the address of this download page to a few of my friends. My Internet connection promptly became entirely unusable – I could not surf the web, send e-mail, or do anything else with my connection.

While putting the file on a web server is a more efficient means of transferring it than sending it as an e-mail attachment would be (since the overhead of the Base-64 encoding is avoided), I had not considered that uploading that much data through a cable modem would eliminate my ability to use that cable modem connection to do anything else at the same time. Every networked application (web surfing, e-mail,etc.) requires bandwidth, and will not be possible if all the bandwidth is consumed by an immense file transfer. Therefore, if (as my web server's logs indicated) four people attempted to download the `SuperBowl.mpg` file from me, my connection would become unusable. Indeed, since cable modem capacity is typically shared with neighbors, I might well even effectively have prevented my neighbors from surfing the web. In an experiment that was conducted later, even one transmission was enough to cause a noticeable effect on my Internet connection.

Later I decided that I really would rather be able to check my e-mail than be able to upload the Super Bowl over the web. I stopped the experiment, and I concluded that sharing the file over the web from my home network was also infeasible.

4.5 Placing it on a P2P file-sharing network

As I noted earlier, I deliberately refrained from posting the `SuperBowl.mpg` file on a public P2P file-sharing network because I did not want to be responsible for its uncontrolled redistribution to the public. I preferred to keep any distribution resulting from my experiments carefully controlled. My experiments, however, indicate to me that I had nothing to fear, since P2P network users would not actually have been able to download the file even if I had actually chose to make it available this way.

I am confident, on the basis of my attempts at e-mail and web distribution, that I can predict what would have happened.

[25] I am an RCN customer, and it is unclear whether doing this experiment is against my Internet Access Agreement; however I am not a lawyer and am not equipped to fully evaluate that document.

By setting up my own web server to allow people to directly download the MPEG from me, I have effectively set up a peer-to-peer file exchange, since another user connects directly to my personal computer[26]. Having people download from my web server was deemed infeasible, therefore sharing the content via a P2P client will be just as difficult.

Basically, moving the file via the network from my apartment through my broadband connection was just not going to happen.

4.6 Moving it to a place with more bandwidth

I decided that I needed to move the files *physically* to some place where I had a higher bandwidth connection to try moving them across – and I realized that such a place was my office at the MIT Media Lab.

Physically moving these HDTV recording files is not a trivial operation, however; a 43 GB file is not a trivial one to move around, if we consider the standard common portable physical data storage media[27]:

1. The 1.44 MB floppy disk (a.k.a. 3.5" floppy) used to be the most common way to physically move data. As they can only hold 1.44MB, it would take over 30,500 floppy disks to store `SuperBowl.mpg`. According to `pricewatch.com`, I can buy 50 floppy disks for $9.97 – so the cost of the media is about $6,100. The transfer rate to the drive is about 500 kilobits/sec, so if I were to hire a temporary employee to swap the disks every 23 seconds, day and night, it would take him or her well over 8 days to copy the entire show to 3.5" floppy disks. I would also incur additional labor costs of over $1,300, paying the Commonwealth of Massachusetts minimum wage of $6.75/hour.

2. The Iomega Zip drive has made its way to many personal computers in either an internal or external drive enclosure and the disks hold 250 MB of

[26] Most web sites are currently set up on third party computers. Most people do not host their own content from their residences, but instead lease computers or lease space for a computer in co-location centers that have much higher bandwidth. In order to distribute HDTV content through these co-location centers, a user would need to upload the data to their web server via their residential connection (an operation that would take many days), and then others would need to download the data from that web server. This effectively *doubles* all the values I have presented.

[27] There are more obscure physical portable media such as the 2.88 MB floppy disk, the 120 MB superdrive floppy disk, the Iomega Click drive, the Iomega Jazz drive, MiniDisc data, and DAT storage that are not mentioned in this analysis as these storage devices have not pervaded into mainstream personal computers.

data[28]. At this capacity, it will take just over 175 disks and at $8.95 for 4 disks (again, according to `pricewatch.com`) this will cost me $390. With a 2.4 megabit/sec transfer rate[29], and with the patience to switch disks every 100 seconds, a day and a half later the Super Bowl will have been copied to 175 250 MB Zip disks.

3. Almost all personal computers sold today have the ability to record onto CD-R/CD-RW optical discs, and this is probably the most prevalent way to record and distribute data today. The CD-R/RW holds 650 MBs[30] and are incredibly cheap coming in at about $48 for 400[31]. Using these, it would take about 70 discs and would cost relatively little at about $8.40. Using data from `cdspeed2000.com`, the fastest CD-R drive is the Kenwood TrueX which can sustain a write at between 6.75 - 10.8 MB/second transfer. Writing a disc, ignoring the setup time, finishing time, the time it takes to eject the recorded disc, and the time to insert a blank one will take 75 seconds – writing 70 discs for the entire Super Bowl will take about an hour and a half. However, it must be noted that the setup and finishing times are not negligible! In most usage scenarios, the finishing time takes more time than the write itself, so the time (still ignoring the time it takes to physically change the discs) could easily double or triple, giving a total recording time of around three to five hours[32].

4. The upcoming recording medium of choice is the DVD-R/DVD+R/DVD-RW/DVD+RW. Many modern computers are now starting to be equipped with drives capable of writing DVDs. The recordable DVD holds 4.36 GB and buying 100 4X DVD-Rs costs about $175; it would take about 10 DVD-Rs to record the entire program at a cost of $17.50. Hewlett-Packard currently makes DVD drives capable of writing an entire DVD in 15 minutes

[28]The original Zip disk held 100MB of data and the newest holds 750MB – the most common, however, holds 250 MB and so this is what we use for the analysis.

[29]This assumes the 250 MB internal ATAPI drive, the fastest Iomega 250 MB disk drive. All USB external 250 MB drives run at 800 kilobits/sec (the same speed as my uplink connection to the Internet). There does exist a 250 MB external Zip drive that uses a fast SCSI connection; however, it is rare, as many personal computers do not have an external SCSI connector.

[30]Some personal computers do have the ability to record 800 MBs onto a CD-R, however most commercially available compact disc recording software does not have this ability.

[31]CD-RWs currently cost significantly more at $78 for 200.

[32]As this is the length of the program itself, this is similar to making a VHS copy, but less convenient because of the need to change media constantly.

(also ignoring – as we ignored above – other times such as preparing, finishing, ejecting discs) meaning that writing all 10 discs would take 2 and a half hours. Again, this number could easily double or triple depending on the other times involved.

While most people are familiar with copying files to media, there is no standard way to split such a large file into smaller ones that can be transported in pieces on the different media to be reconstructed on a later place; specialized software must be obtained for this task.

Even though I do have a DVD-R burner in my possession, I do not wish to free the funds to purchase 500 DVD-Rs at the bulk price of $500. So, in order to purchase DVDs in more modest quantities (by walking down to my local CompUSA store, for example), a 10-Pack of DVD-R Media would cost me $36.99 – still a little expensive for the one-time ability for me to bring the data to my office or for me to physically give it to my best friend.

Luckily I own a 170 GB external FireWire (IEEE 1394) hard drive, so I transferred the `SuperBowl.mpg` file to the drive. Even though the FireWire bus is rated at 400 megabits/sec, it still took 25 minutes instead of the predicted 15 minutes for me to move this massive file, demonstrating again that devices rarely achieve their theoretical maximum transfer rates in practice. I unplugged the removable hard drive from my computer, put it in my backpack, and headed off to my office[33].

4.7 While at my office

Now that I was sitting at my office at MIT, I decided to experiment with the substantially greater network bandwidth that an institution like MIT put at my disposal relative to the limited capacity of consumer broadband[34]. First off, the

[33]Computing the throughput of the data to my office while be transported in my backpack is possible. The commute time from my apartment to my office is 25-30 minutes, while in the summer it may take as little as 15 minutes. I have omitted the "commuting" computation, however if it were included the resulting bandwidth calculation would be in the range of 240000 to 500000 kilobits/sec – that is a 300 to 500 times speed-up over my cable modem. Note that this "sneakernet" scenario is one that is explicitly permitted in the broadcast flag proposal, which allows for output to serial-copy-restricted media such as DVHS cassettes. In the present technological milieu, "sneakernet" is the *only* "network" capable of moving captured ATSC content at reasonable speeds, and is likewise the *only* "network" that the MPAA, et, al., propose to permit with this mandate.

[34]The MIT network topology is published at `http://web.mit.edu/network/mit-net.html`. It shows that the majority of "on-

outgoing mail server that I was attempting to send to from home was on the same 100 Base-TX network that I was on, so I retried e-mailing the `SuperBowl.mpg` to my friend.

But it still did not work.

Actually, I was a little surprised. I sent the message and waited for three days; even though my computer appeared to send the message properly, my friend never received it. Nor did I ever receive any error or bounce message indicating that delivery had failed. The message simply disappeared. This completely puzzled me, as I believed I had waited more than enough time for the mail to leave my office computer and make its way to the outgoing mail server. I asked some people knowledgeable about the MIT network and e-mail what might have become of my e-mail message. They looked at me, puzzled at first (as if questioning my

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campus" MIT is connected by, at worst, 100 Base-TX Ethernet and a lot of it is interconnected by gigabit Ethernet. Running to off campus living groups (FSILGs) is a single shared T3 (45 megabit/sec) line. Running to the Harvard campus is a dedicated OC-12 fibre line, running to `NOX.ORG` (the Northern Crossroads where New England campuses have fibre, high bandwidth, low hop count, links too) is another OC-12 fibre, to MediaOne is an OC-3 fibre, and lastly to Genuity (presumably where MIT meets the Internet) is another OC-3 fibre. Distilling all this down it means that from my office to

1. the rest of MIT campus, I have somewhere between 100 megabits-gigabit/sec of connectivity.
2. to MIT off campus, if all goes well, from my computer to another MIT computer off campus I will be able to achieve a 45 megabit/sec connection
3. to Harvard or any school cooperating on `NOX.ORG` (presumably when connecting to Harvard there will be a better connection than when connected to another computer through `NOX.ORG` as there are less hops to move through), there should be at best about a 622 megabits/sec connection. Realistically this is *extremely* optimistic as this also suffers from the "weakest link" – for example, Northeastern only has an OS-3 link to `NOX.ORG` which means that even though the MIT network can insert data at 622 megabits/sec, Northeastern can only receive it at 155 megabits/sec. There is also no guarantee that the internal campus links that other schools use can handle the bandwidth they are connected to `NOX.ORG` with.
4. to the MediaOne network and the rest of the world (via Genuity), MIT has a 155 megabit/sec connection.

The only guarantees on any speed connection is within the MIT campus, and even that is problematic. By running a small end-to-end bandwidth test between my office computer and another computer that is physically on the other end of the MIT campus (5 hops away according to traceroute), I can achieve a 25 megabit connection – only a quarter of the reported capacity of the physical link on a random Thursday afternoon. The rest of the network was probably "busy".

Location	No. MB downloaded	Avg. Transfer Speed	Time to Finish	% Saturation
Somerville, MA	641 MB	1.36 megabit/sec	3 days	90.7%
Dallas, TX	920 MB	2.04 megabit/sec	2 days	68.0%
San Francisco, CA	414 MB	920 kilobit/sec	4.5 days	61.3%

Table 1: The summary of three test runs of downloading `SuperBowl.mpg` for an hour from a web server at the MIT Media Lab through the residential broadband connections detailed in table 2.

quixotic desire to send a 43 GB file through e-mail), and then they politely informed me that the mail server was programmed to reject any mail larger than a few megabytes. That is, my message was about 430,000% larger than MIT's mail server was prepared to handle. They found it curious that no error mail was returned to me – but they chalked it up to my "stupidity" and perversity in attempting to e-mail a 43 GB file.

I again set up a shared folder over the Windows network and other computers at the lab on the wired Ethernet could watch the Super Bowl just fine – but again, as I had earlier experienced, the laptops roaming around on the 802.11b displayed stuttering video. A colleague at MIT, whose computer is physically located on the other side of the MIT campus, tried to stream the file from me across the MIT campus network, and could just barely maintain a connection that was fast enough to watch the video in real time. He wrote me a note saying that he would let it download for about an hour than start watching it while it continued to download in the background because, at that time, the campus network was just fast enough to mostly maintain a continuous live stream, and he found the stuttering irritating.

Since I was trying to recreate all my previous experiments in the campus network context, I installed the Apache web server on my office computer and made the MPEG file available again. I had no delusions that my experiment would saturate the MIT network, so I asked three friends who were off the MIT campus and who were technically knowledgeable residential broadband users to download the file from my office for an hour to see how many bits they could download. The results are tabulated in Table 1.

As predicted, all three of these combined did not saturate the network connection in my office (or on the MIT campus); however, each downloader was apparently downloading as quickly as he or she could. None of these friends would be able to download the 5 hour show in any reasonable amount of time to watch it –

Location	Distance from MIT Media Lab (in network hops)	Max. Advertised Download Speed
Somerville, MA	9	1.5 megabit/sec
Dallas, TX	18	3.0 megabit/sec
San Francisco, CA	21	1.5 megabit/sec

Table 2: The characteristics of the three residential broadband downloaders.

and during the entire download process, their residential Internet connections will have been rendered useless. The fastest downloader, in Dallas, TX, would have to dedicate a broadband connection exclusively for two full days to get a copy.

All in all, even with the faster network connection at the computer I was using, I could not figure out a way to get the file to any other computer at any decent physical distance in a reasonable amount of time.

It is just not possible.

5 In the end

I cannot conceive of a way to ship the entire HDTV captured MPEG-2 recording between any two residential broadband customers in the existing Internet infrastructure; no matter how "fat" the upstream or downstream pipe is in a current apartment or house, transferring the sheer number of bits that comprise a single television show that was broadcast over the air encoded in ATSC is just not feasible. Overcoming the "last mile" problem seems improbable. Even if the bits are recorded in locations with a large amount of bandwidth at the source, transmission to any location that is not local or that is remote via the Internet is not going to have a high enough bitrate to make it feasible. The status quo is not going to be affected by the introduction of this high quality stream – video will still need to be encoded and compressed into different formats such as MPEG-4/DivX[35] or be resized into a smaller resolution for any transmission that is expected to finish in a reasonable amount of time.

What should be noted is that all the numbers presented in this paper exhibit a

[35]MPEG-4/DivX, while being the more prominent video compression scheme for Internet distribution, is "lossy", meaning that a perfect reconstruction of the original video scheme is not possible. The lossiness is so significant, in fact, that the encoded and compressed video is below the quality of traditional NTSC broadcast service.

linear relationship between program length and file size (or program length and transfer time). So, a four-hour recording is about twice as large, and takes about twice as long to copy, as a two-hour recording. The 43 GB file is for a five-hour recording, which means that a one-hour recording occupies about 8.6 GB of space – this still means that it would take

1. a full day for a hour our television show to move out of my house network (because a standard broadband connection only has a 200 kilobit/sec upload speed instead of my 800 kilobit/sec upload – this means an average customer would take 4 full days to ship out),

2. 6116 floppy disks,

3. 14 CD-Rs, or

4. 2 DVDs

to transmit or to hold all the data received over the air. This is still impractical for routine transfers of a short television program, and, in the case of recordable media, still implies a significant media cost and recording time.

In this document, I have shown that the MPAA's view of the capabilities of current and foreseeable networking technologies is misinformed; they have provided a series of reasons to argue that their intellectual property will be distributed more readily as a result of ATSC terrestrial broadcast service than it is presently today, and I have stated why, in my opinion, I deem this to be incorrect and actually impossible. I conclude that there is no practical evidence that an ATSC broadcast flag mandate would address a real problem.